KU LEUVEN

Status of the ^{35}Ar beta-neutrino correlation measurement with WITCH

Paul Finlay, for the WITCH collaboration

BriX Day Fall, December 2nd, 2013

Beta Decay in the Standard Model

$$H_\beta = \frac{G_F}{\sqrt{2}}(\bar{p}\gamma_\mu n)(\bar{e}\gamma^\mu \nu_e) + \text{h.c.}$$

Fermi's hamiltonian for weak interaction did not account for change of spin or parity violation

Parity violation, all types of Lorentz-invariant currents

$$\begin{aligned}\mathcal{H}_\beta = {} & (\bar{p}n)\,[\bar{e}(C_S + C'_S\gamma_5)\nu] \\ & + (\bar{p}\gamma_\mu n)\,[\bar{e}\gamma_\mu(C_V + C'_V\gamma_5)\nu] \\ & + \frac{1}{2}(\bar{p}\sigma_{\lambda\mu} n)\,[\bar{e}\sigma_{\lambda\mu}(C_T + C'_T\gamma_5)\nu] \\ & - (\bar{p}\gamma_\mu\gamma_5 n)\,[\bar{e}\gamma_\mu\gamma_5(C_A + C'_A\gamma_5)\nu] \\ & + (\bar{p}\gamma_5 n)\,[\bar{e}\gamma_5(C_P + C'_P\gamma_5)\nu] + \text{h.c.}\end{aligned}$$

Assumptions

$(|C_i| = |C'_i|)$ Maximal parity violation

pure V-A structure — All S, P, T couplings are 0

no $\mathcal{T}$ violation — All C_i real

$C_V = C'_V$ is equal to 1 — CVC

$(C_P = C'_P = 0)$

$$|C_S^{(\prime)}/C_V| < 0.07, \quad |C_T^{(\prime)}/C_A| < 0.09.$$

KU LEUVEN

Correlation Coefficients

Angular distribution of electron and neutrino in beta decay of a polarized nucleus determined by amplitudes of interactions via correlation coefficients:

$$\omega(\langle \mathbf{J} \rangle | E_e, \Omega_e, \Omega_\nu)\, dE_e\, d\Omega_e\, d\Omega_\nu$$

$$= \frac{F(\pm Z, E_e)}{(2\pi)^5} p_e E_e (E_0 - E_e)^2\, dE_e\, d\Omega_e\, d\Omega_\nu$$

$$\times \frac{1}{2}\xi \left\{ 1 + a \frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b \frac{m}{E_e} + \frac{\langle \mathbf{J} \rangle}{J} \cdot \left[A \frac{\mathbf{p}_e}{E_e} + B \frac{\mathbf{p}_\nu}{E_\nu} + D \frac{\mathbf{p}_e \times \mathbf{p}_\nu}{E_e E_\nu} \right] \right\}$$

Beta-neutrino angular correlation, independent of nuclear polarization

Fierz interference, final-state effect independent of any spin or momentum

Beta asymmetry parameter, product of nuclear spin and beta particle's momentum

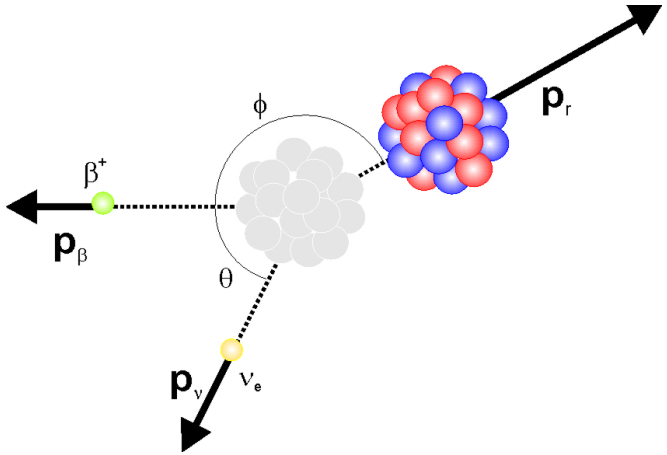
$$\tilde{X} = \frac{X}{1 + \langle b' \rangle}$$

$$b' \equiv (m / E_e) b$$

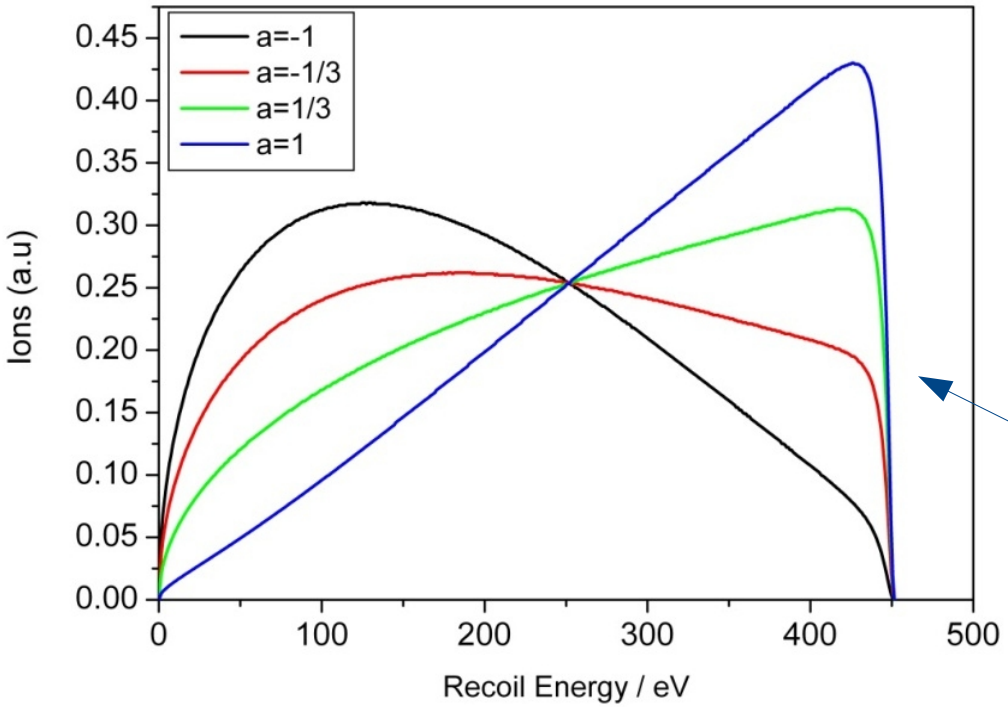
KU LEUVEN

Beta-Neutrino Angular Correlation

$$W(\theta) = 1 + \frac{p_\beta \cdot p_\nu \cdot cos(\theta)}{E_\beta \cdot E_\nu}\tilde{a}$$



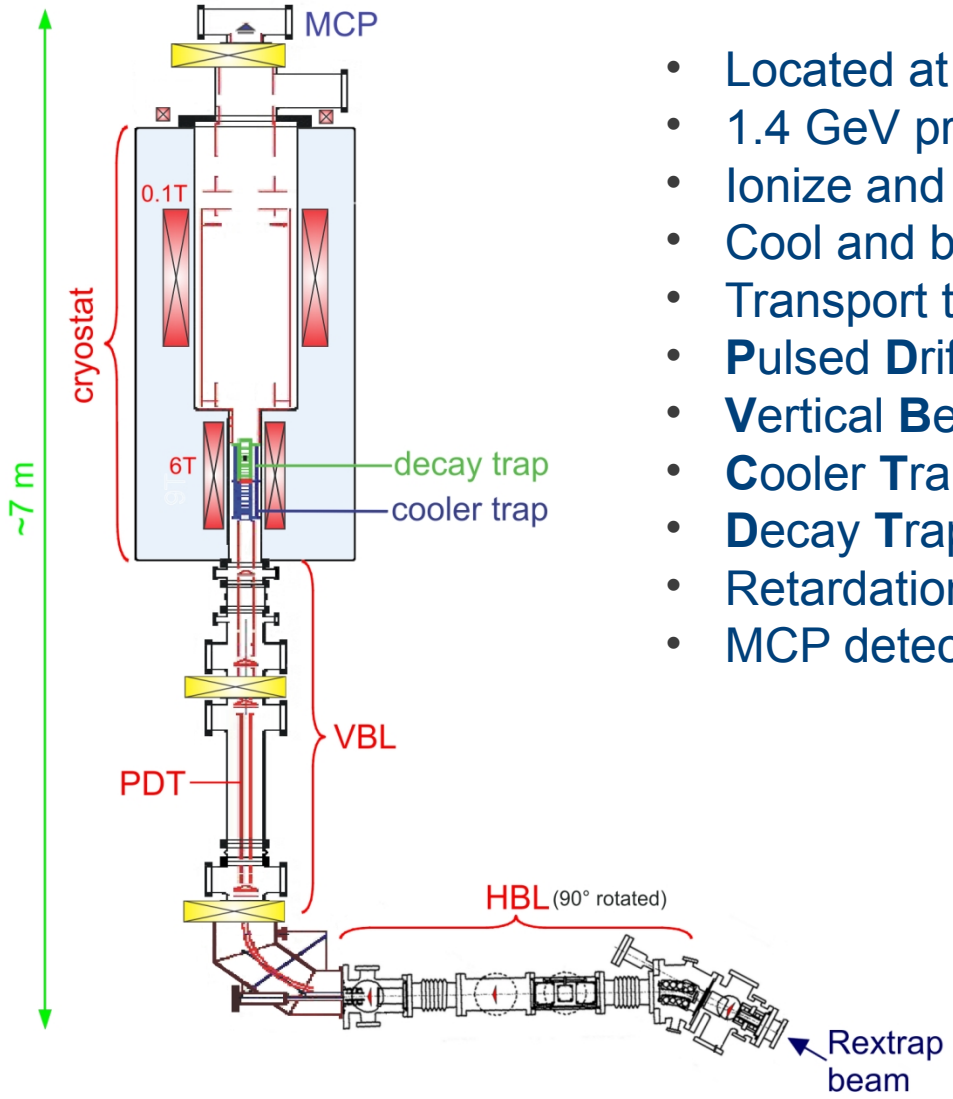
Angle between emitted beta and neutrino determined by *a*



Energy spectrum of recoiling nucleus determined by *a*

KU LEUVEN

WITCH setup

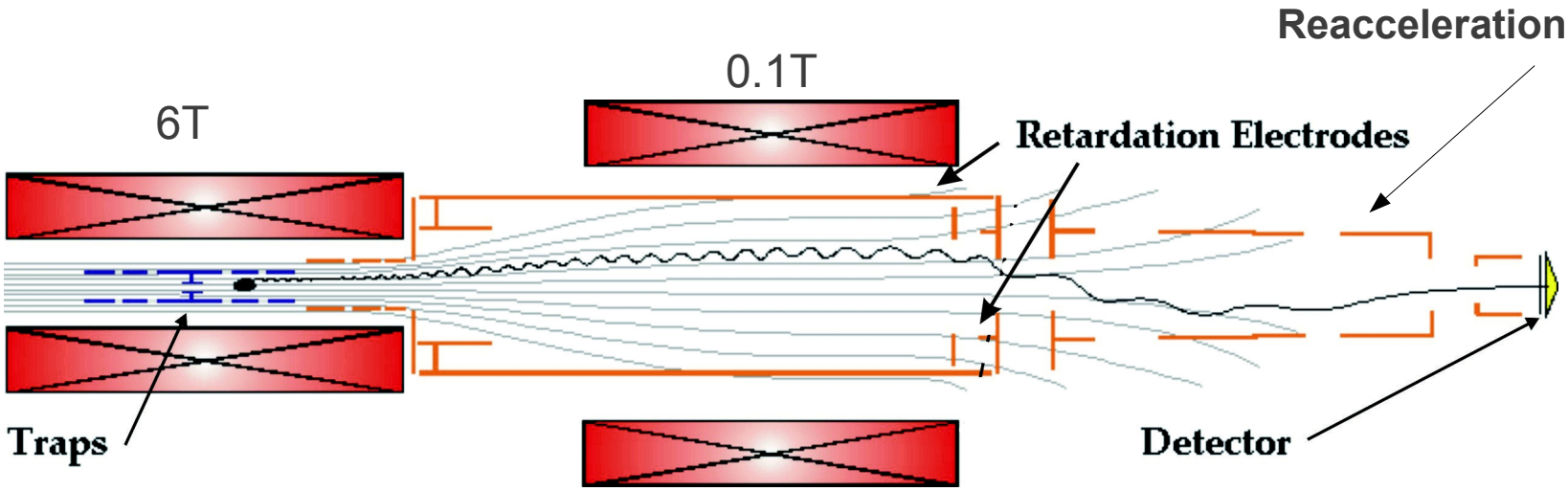


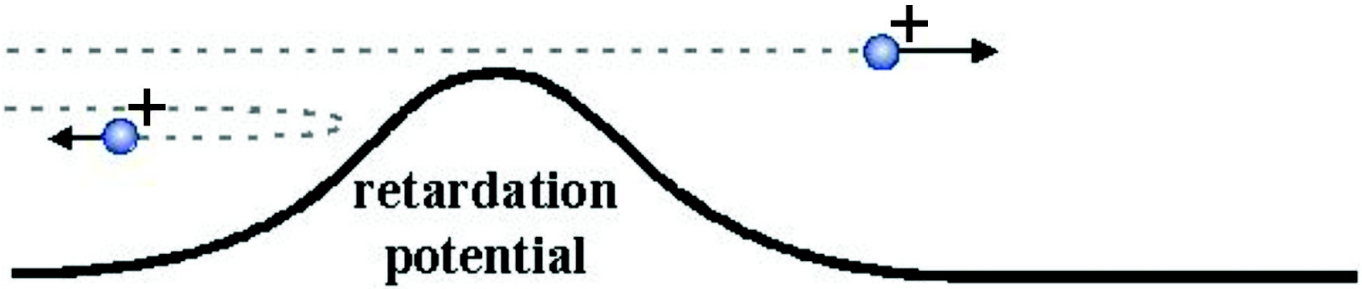
- Located at CERN-ISOLDE
- 1.4 GeV protons on solid target
- Ionize and mass separate products (^{35}Ar)
- Cool and bunch in REXtrap → 30 keV
- Transport through **H**orizontal **B**eam **L**ine
- **P**ulsed **D**rift **T**ube reduce total energy ~0
- **V**ertical **B**eam **L**ine decelerates ions
- **C**ooler **T**rap (buffer gas) cool/center ions
- **D**ecay **T**rap to store scattering free source
- Retardation Spectrometer for energy analysis
- MCP detector as ion counter

References:
M. Tandecki et al., NIMA 629 (2011) 396-405.
E. Traykov et al., NIMA 648 (2011) 1-14.
S. Van Gorp et al., NIMA 638 (2011) 192-200
M. Beck et al., NIMA 503 (2003) 567
M. Beck et al., EPJA 47 (2011) 45.

KU LEUVEN

WITCH Spectrometer

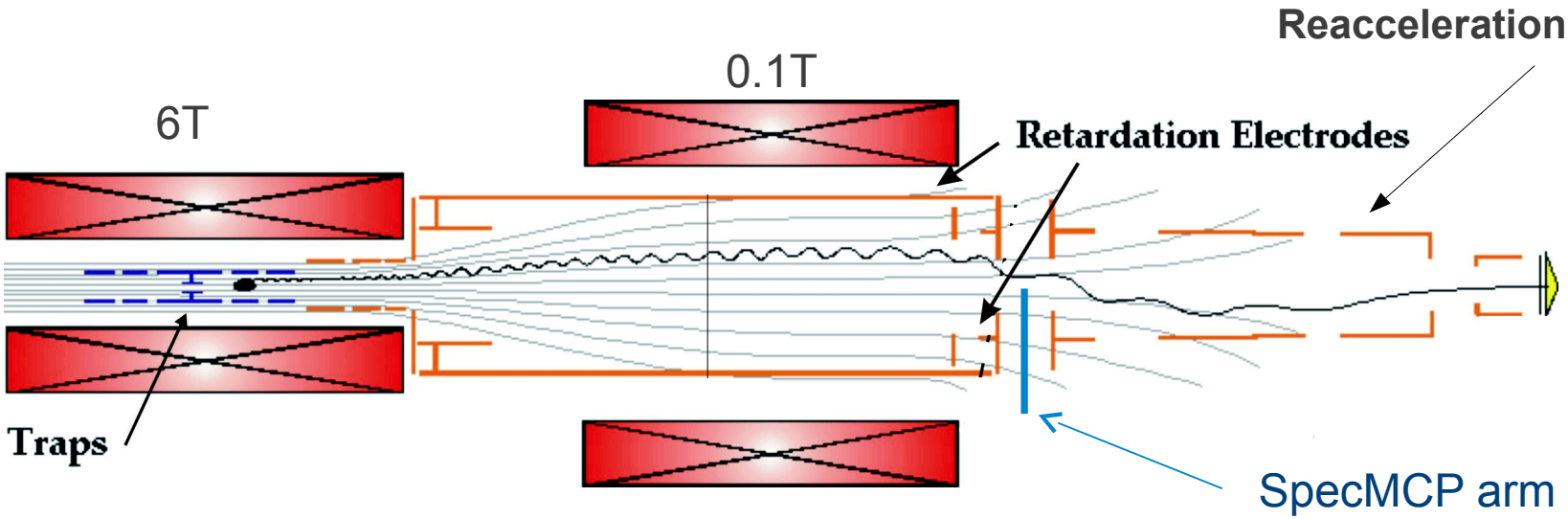




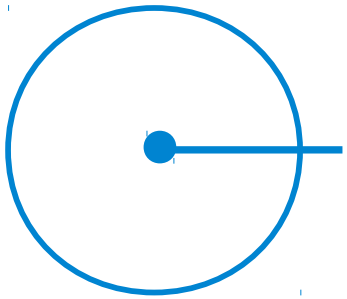
Conversion of radial energy = $1-B_{spec}/B_{trap} = 98.3\%$

KU LEUVEN

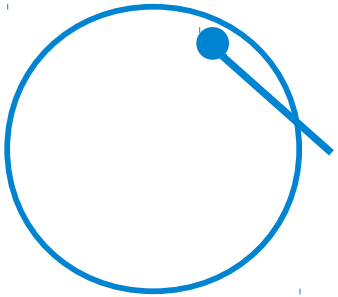
Diagnostic MCP on movable arm

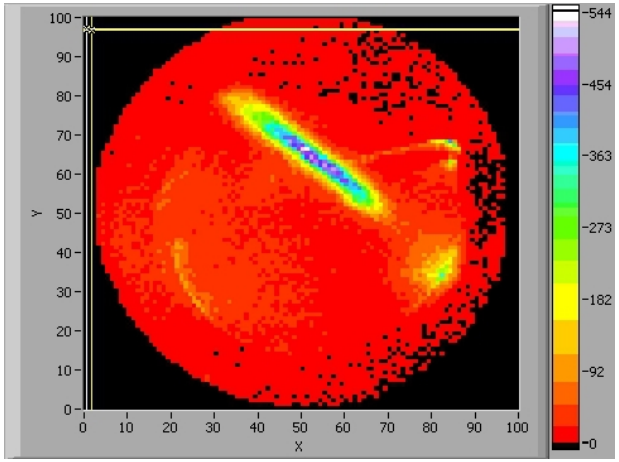


SpecMCP in



SpecMCP out

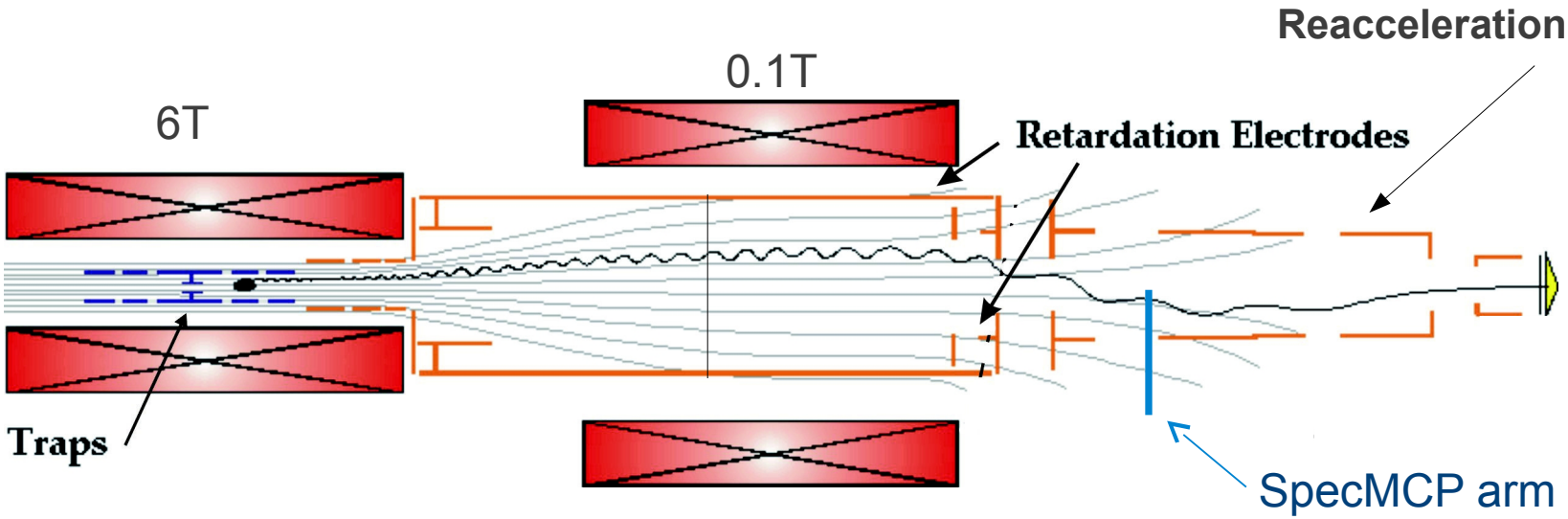




Even when out:
Grounded arm between -2kV and -7 kV

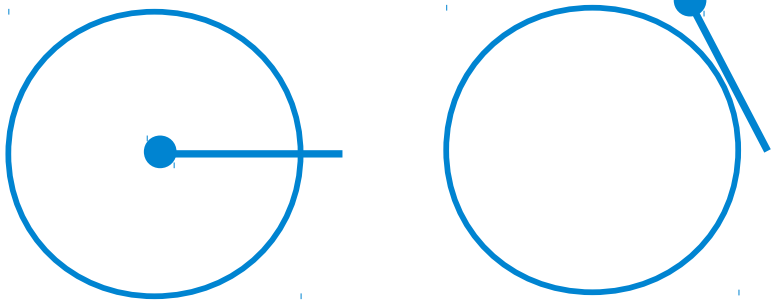
KU LEUVEN

Diagnostic MCP on movable arm

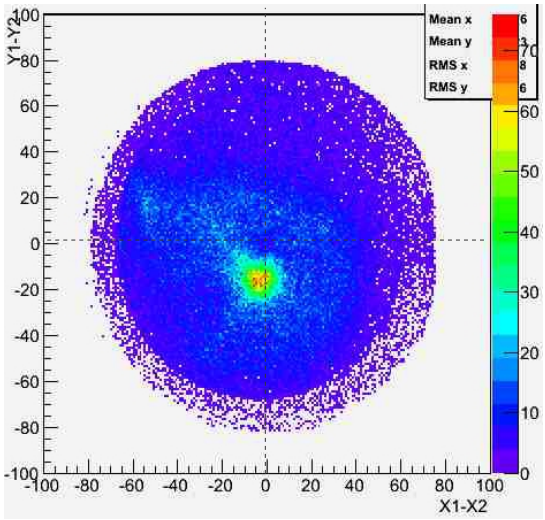


SpecMCP in

SpecMCP out



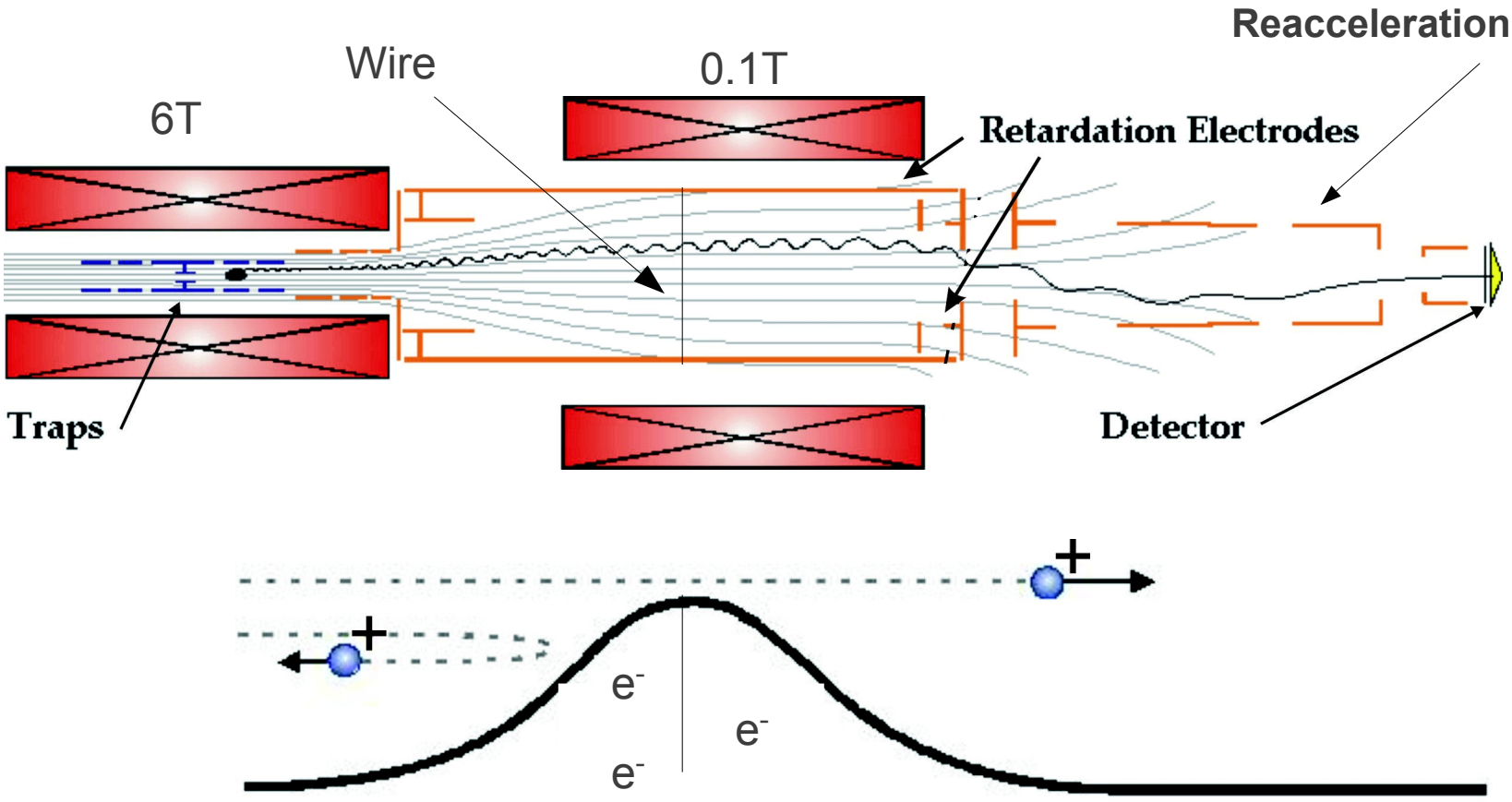
Moving the SpecMCP axially



Even when out:
Grounded arm between -2kV and -0.4 kV

KU LEUVEN

Anti-ionization wire



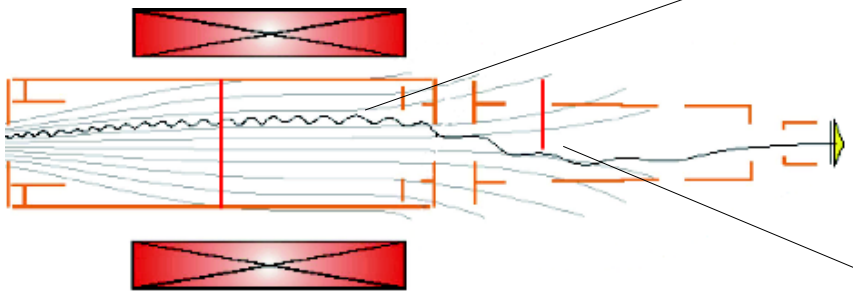
Grounded wire removes electrons trapped in the blocking potential well

KU LEUVEN

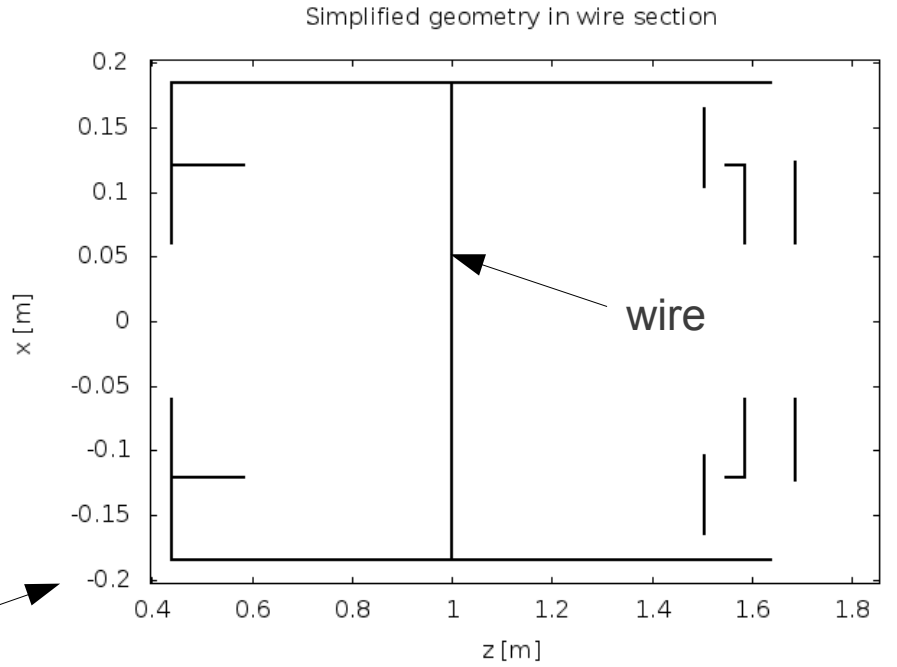
Electric potential calculations

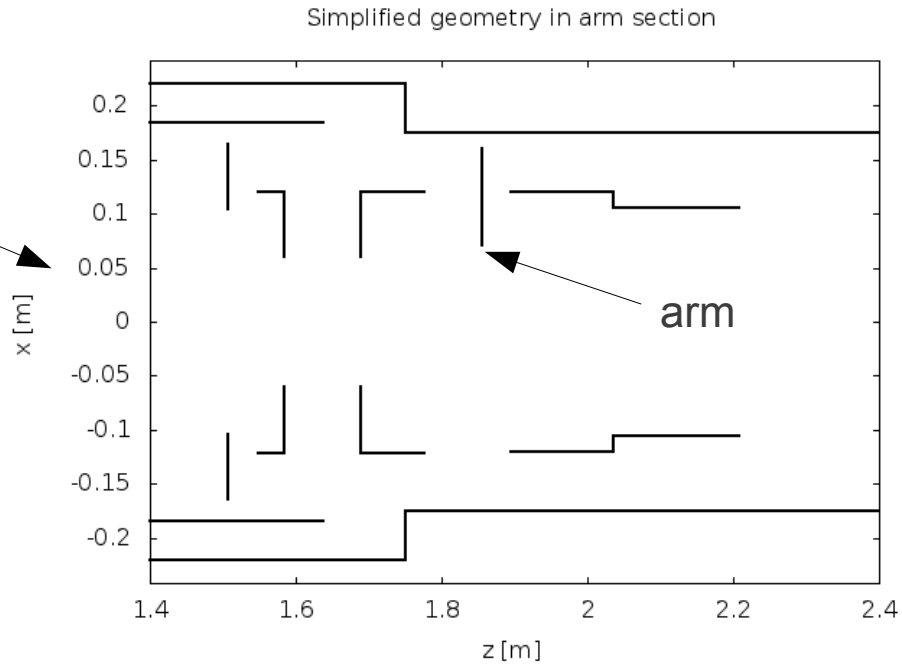
Calculations of electrical potential:

- **2D** – full geometry
  – without wire/arm

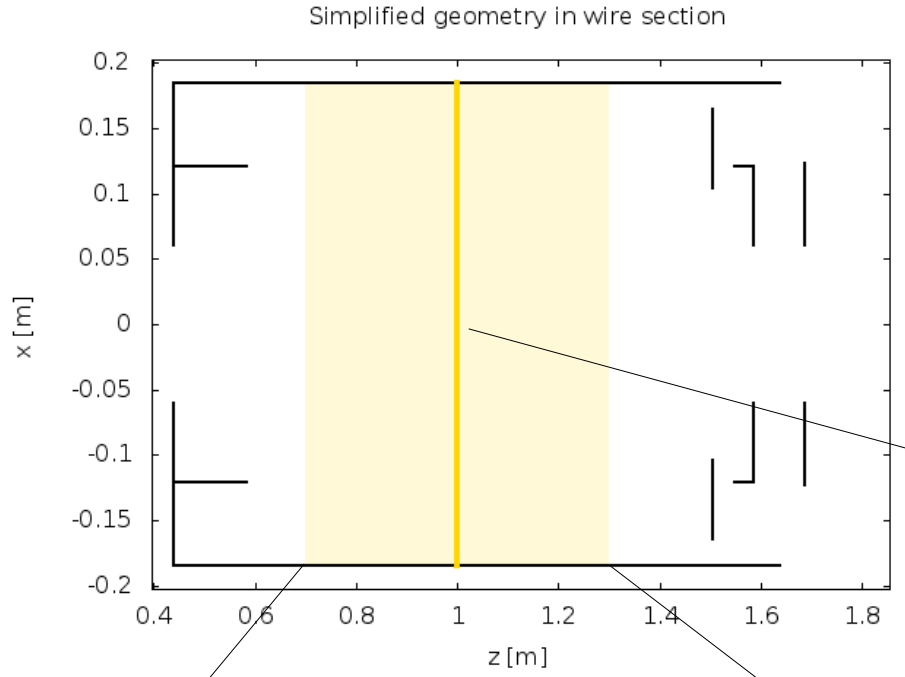


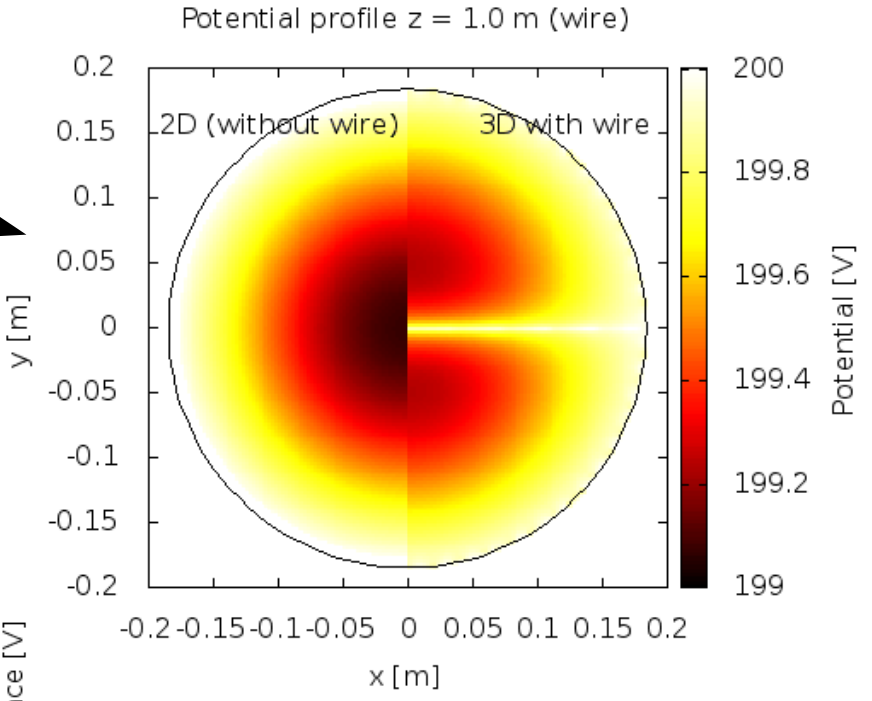
- **3D** – simplified geometry:
  – without wire/arm
  – with wire/arm

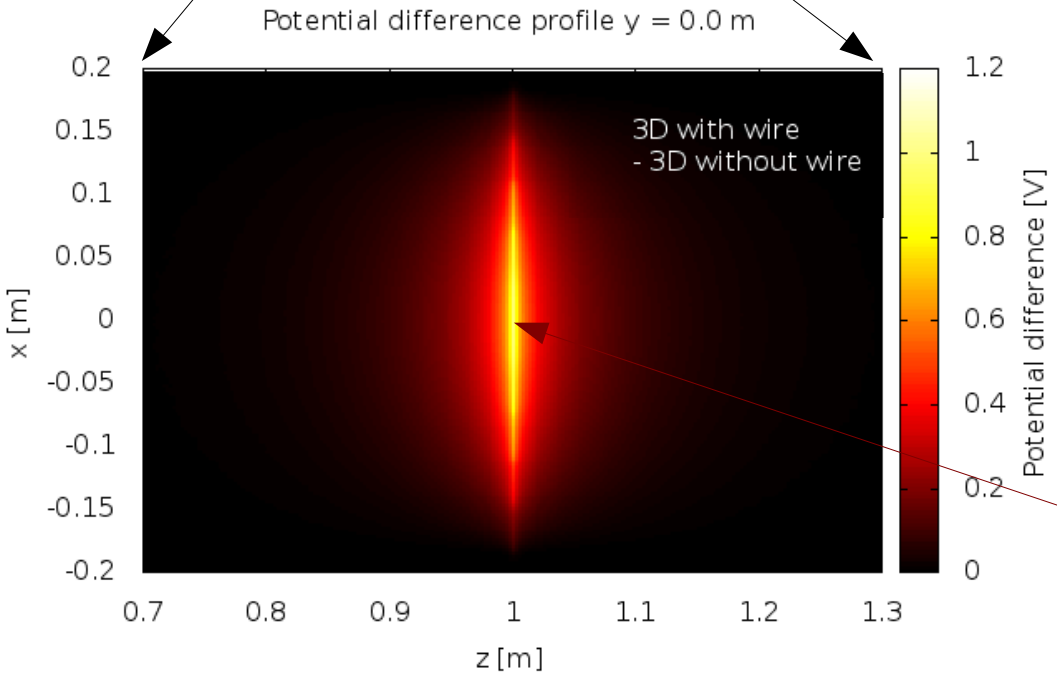




Wire

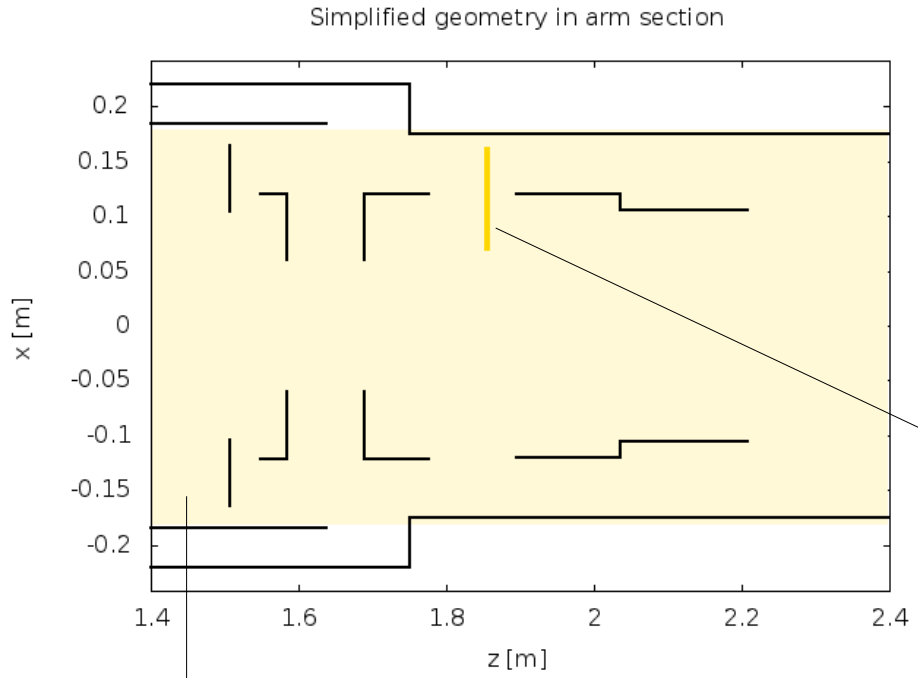


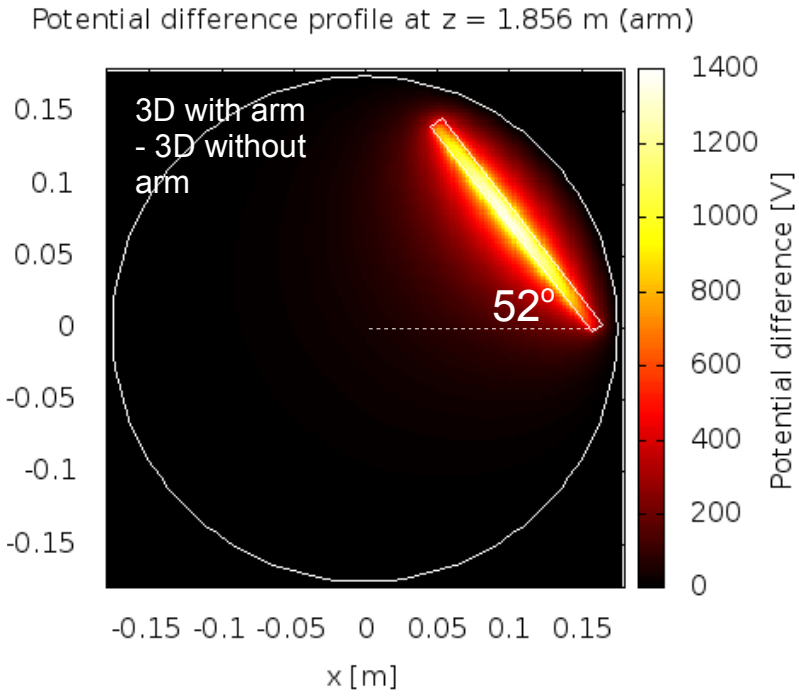


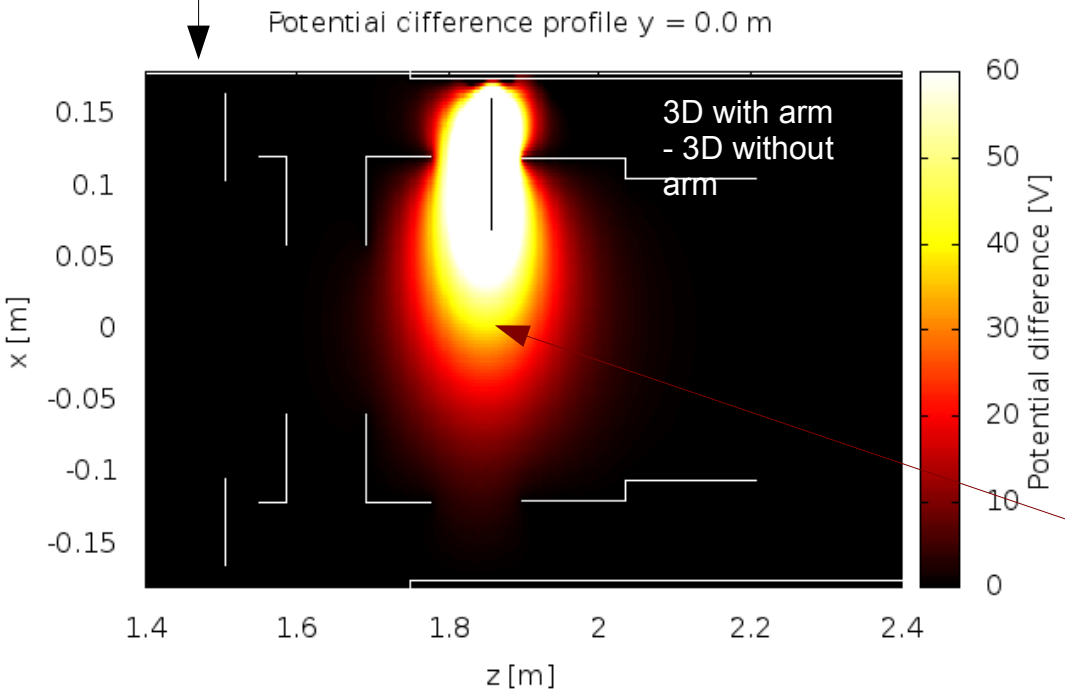


The wire rises the potential in the centre by ~1.1 V (0.5%)

Arm

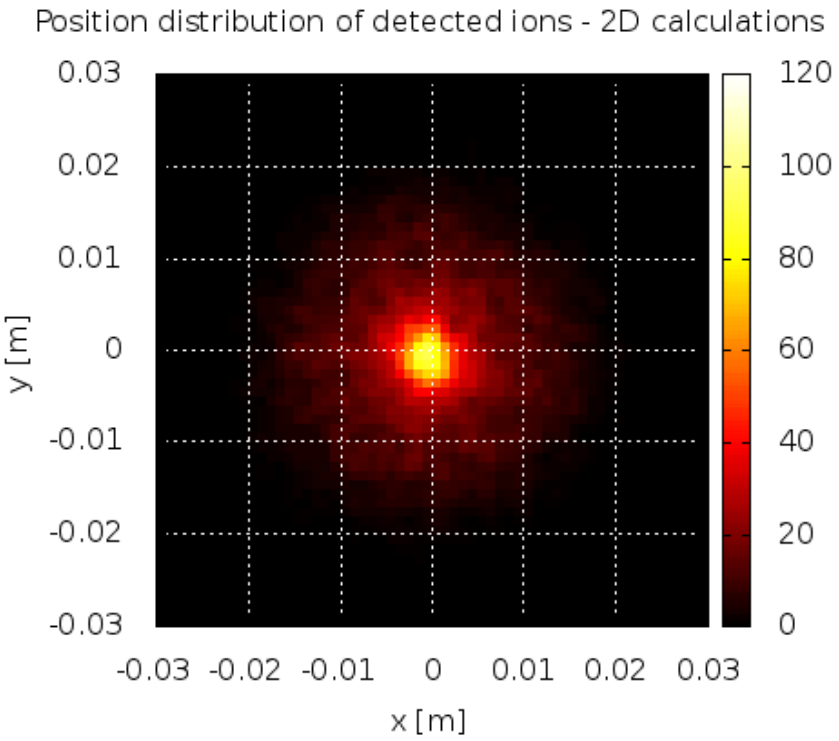


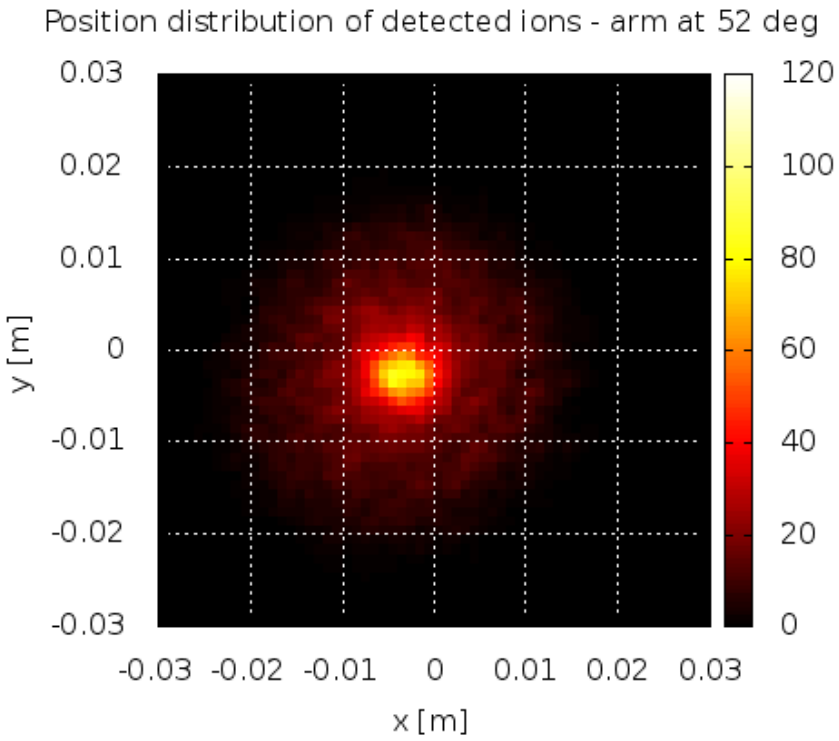




The potential in the centre (0, 0, 1.855) is higher by ~38 V (1.3%)

Preliminary results





The arm is deflecting ions!

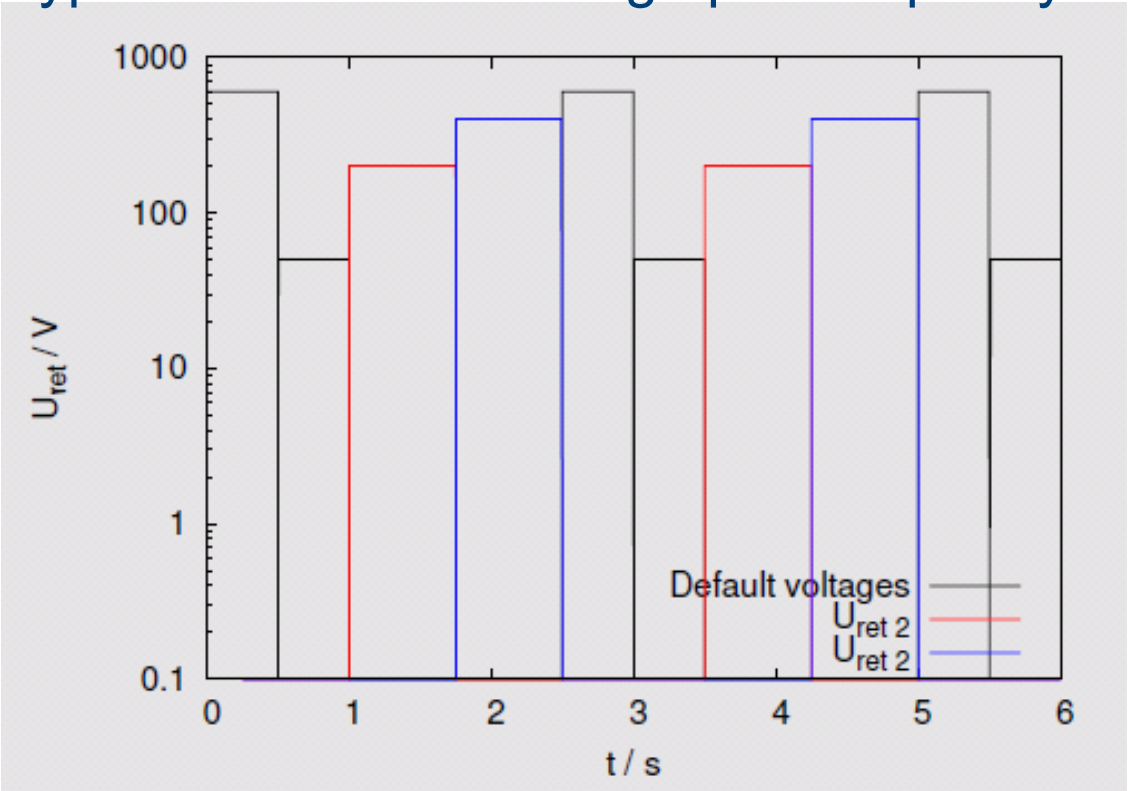
Online experiment 2012

Statistics from Experiment

- 14 shifts @ 8 hours
- 90 recoil ion runs
- 27k cycles @ 6s
- 25M counts in total

Dedicated background, half-life, ion cloud energy and efficiency calibration measurements before, during, and after experiment

Typical retardation voltage pattern per cycle



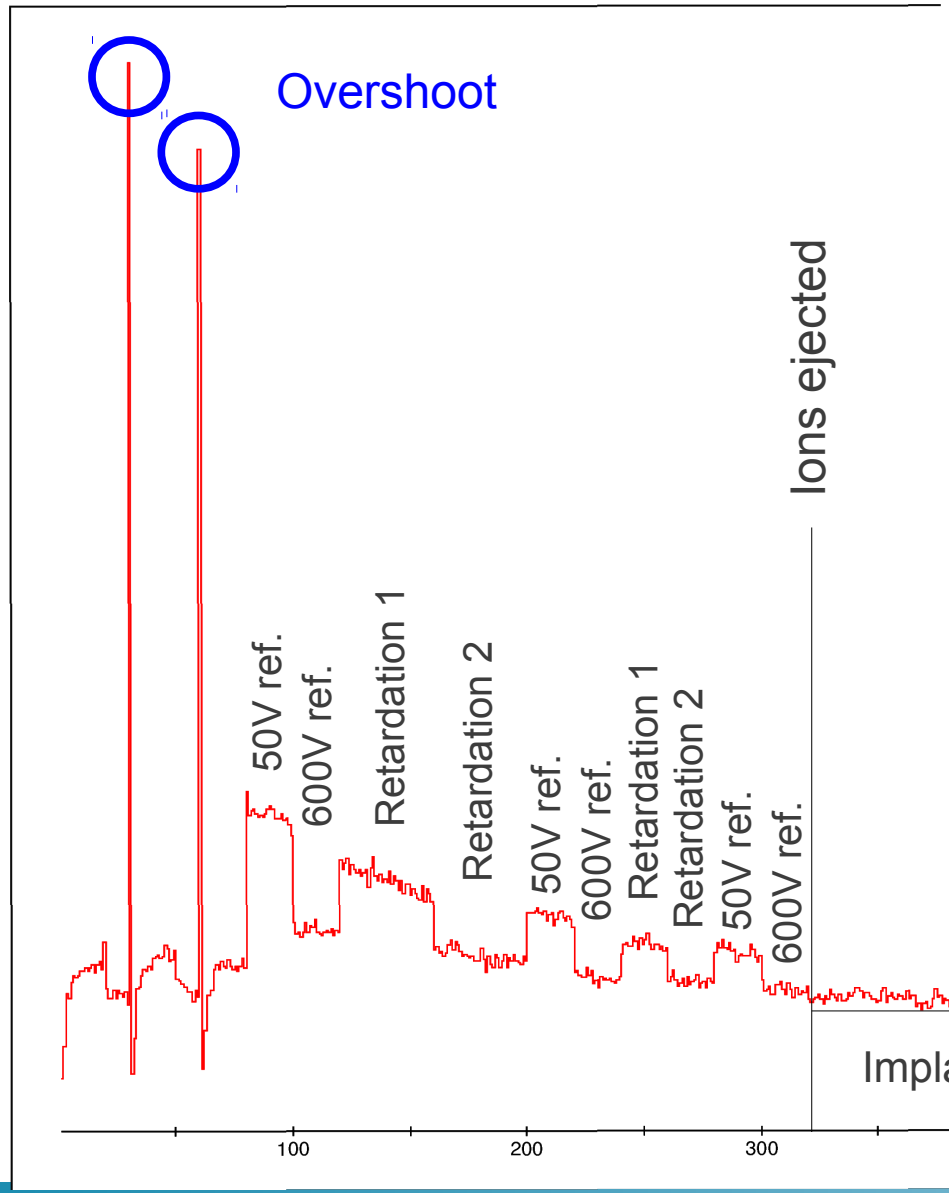
2 reference voltages (50V, 600V)
2 measurement voltages
(~20 different values spanning recoil spectrum)

KU LEUVEN

Typical ^{35}Ar Cycle

$T_{1/2}(^{35}Ar) = 1.775(4)$ s

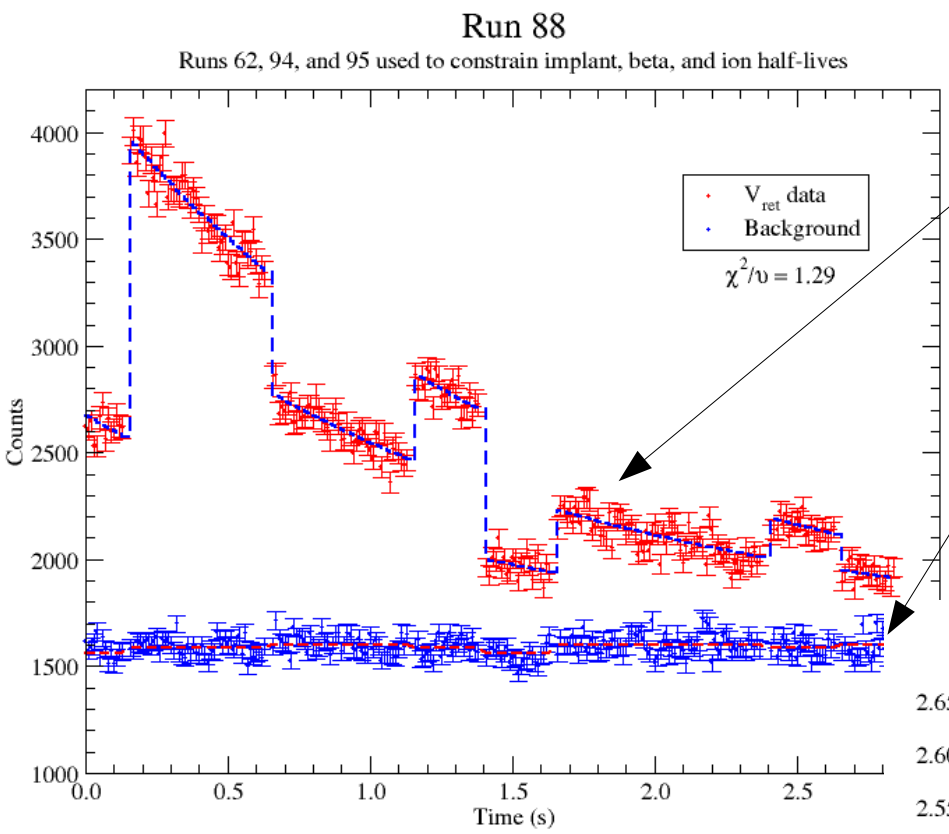
Recoil endpoint = 452 eV



- Two effective half-lives:
  - **Trap** = True $T_{1/2}$ + losses
  - **Implant** = True $T_{1/2}$ + diffusion
- Three detected signals:
  - **Trap** = Recoils and betas
  - **Implant** = Decay of ions

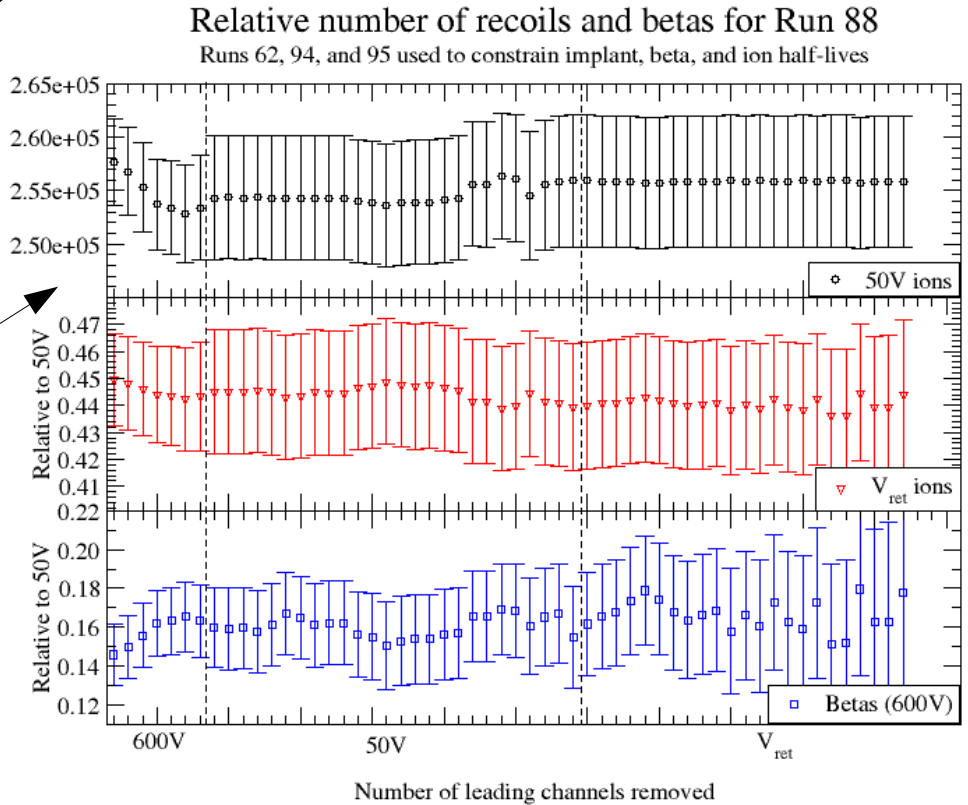
- Trap and beta activity present before ejection
- Implantation activity present during whole cycle
- Need to account for implantation and beta activity → background under our recoil signal

KU LEUVEN



Recoil ions, betas, and implantation activity constrained in fits by dedicated measurements

Dedicated cycles to constrain voltage-dependence of background



Some problems at early times during fit, PDT recharging/MCP recovering(?)

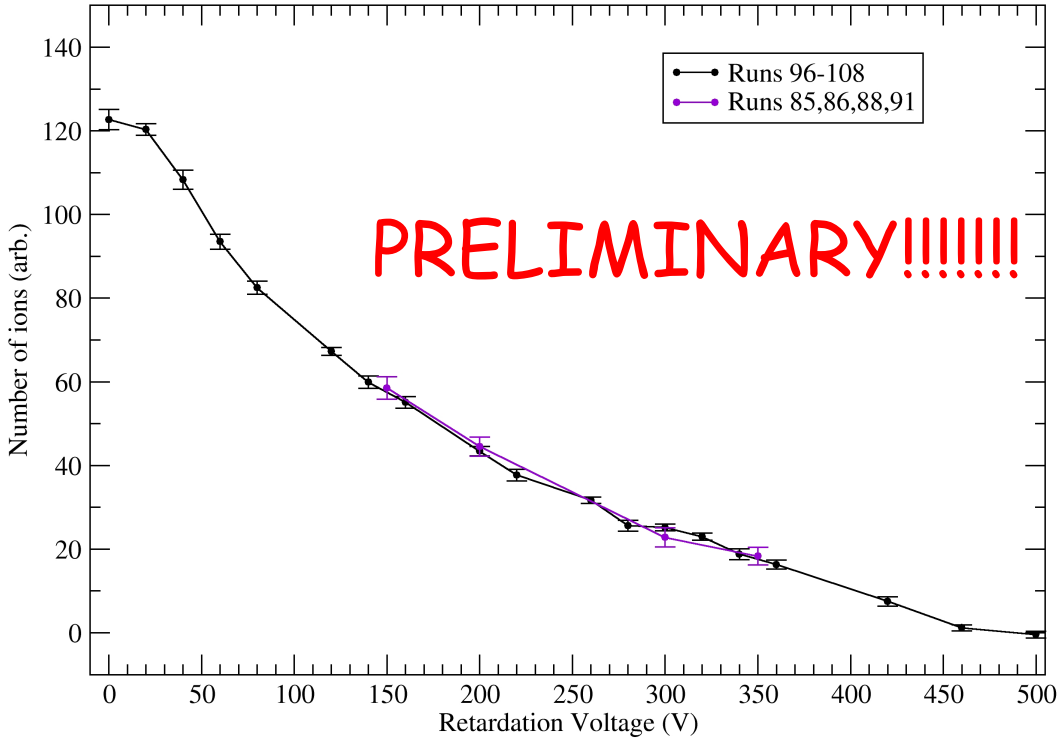
Otherwise consistent, statistically behaved data

Preliminary results

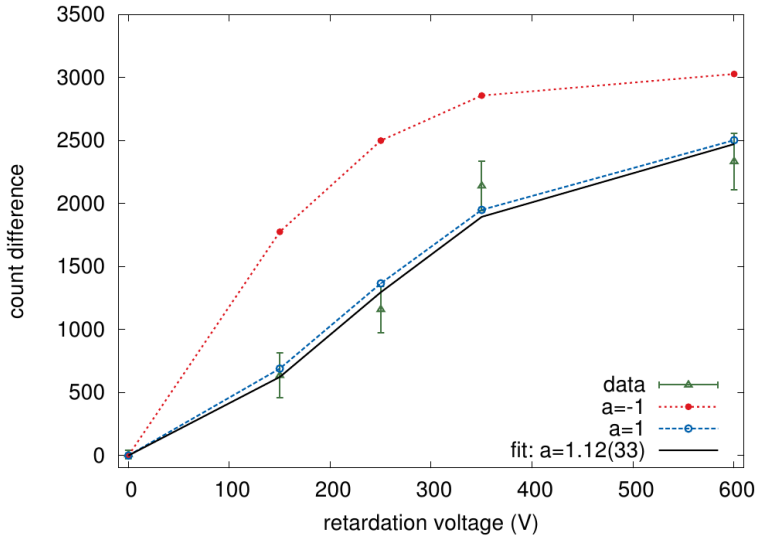
2011:
- 4 data points
- 30% statistical uncertainty

2012:
- 23 data points
- Few % statistical uncertainty

2012
Integral recoil spectrum
(normalized to 50V)



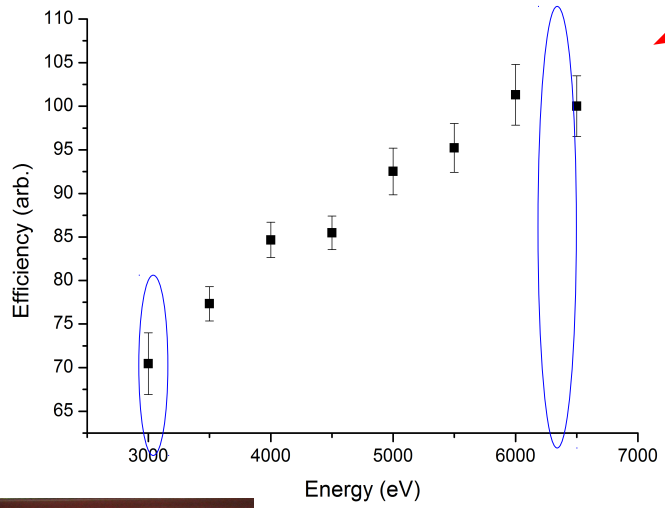
2011
Differential recoil spectrum



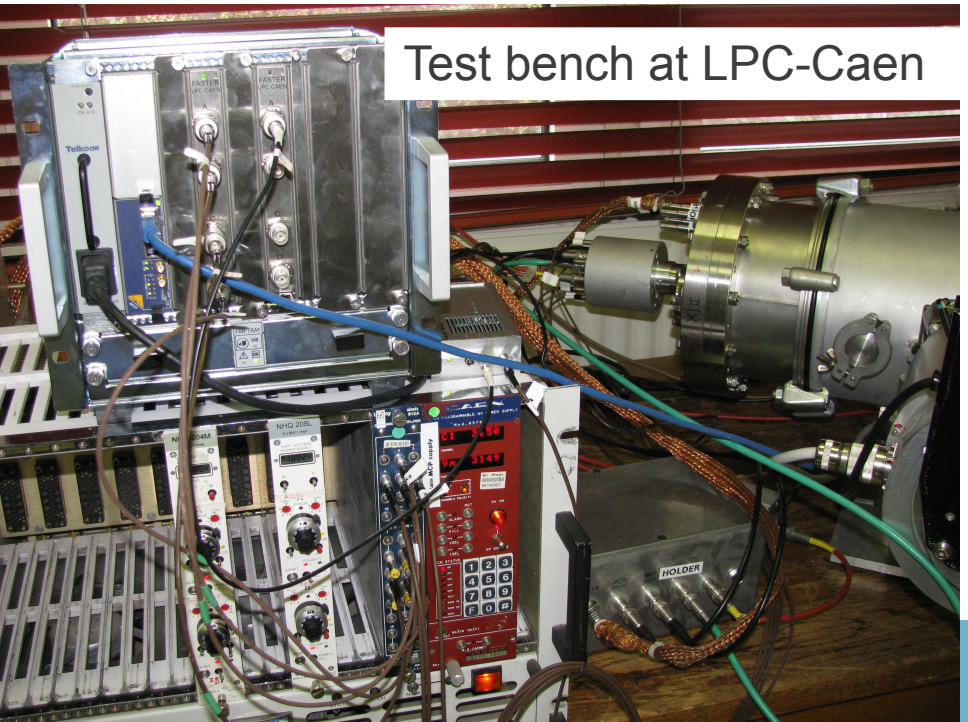
KU LEUVEN

Systematics – Energy Dependent Efficiency

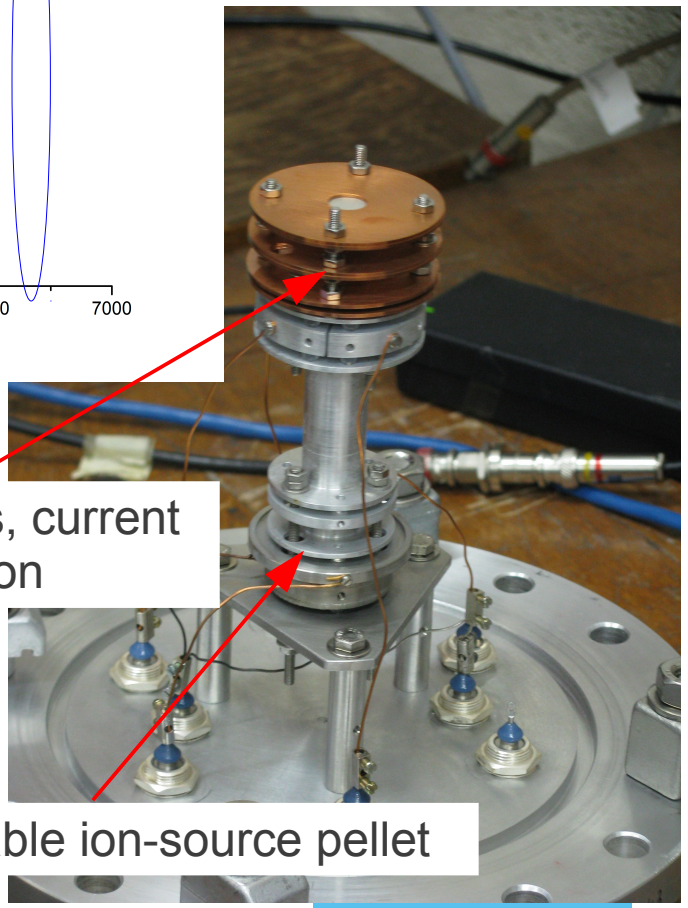
- Measured detection efficiency as a function of energy with Na ions
- Repeat with K, better current normalization in 2014



Efficiency varies by 30% over 1+ and 2+ recoil ion energies



Test bench at LPC-Caen



Attenuators, current normalization

Exchangeable ion-source pellet

KU LEUVEN

Collaboration

KU Leuven
N. Severijns
P. Bączyk
M. Breitenfeldt
P. Finlay
T. Porobic
E. Wursten
G. Soti

TRIUMF
M. Tandecki

FAIR
A. Herlert

Universität Münster
Ch. Weinheimer
P. Friedag

RIKEN
S. Van Gorp

PSI
A. Knecht

Universität Mainz
M. Beck

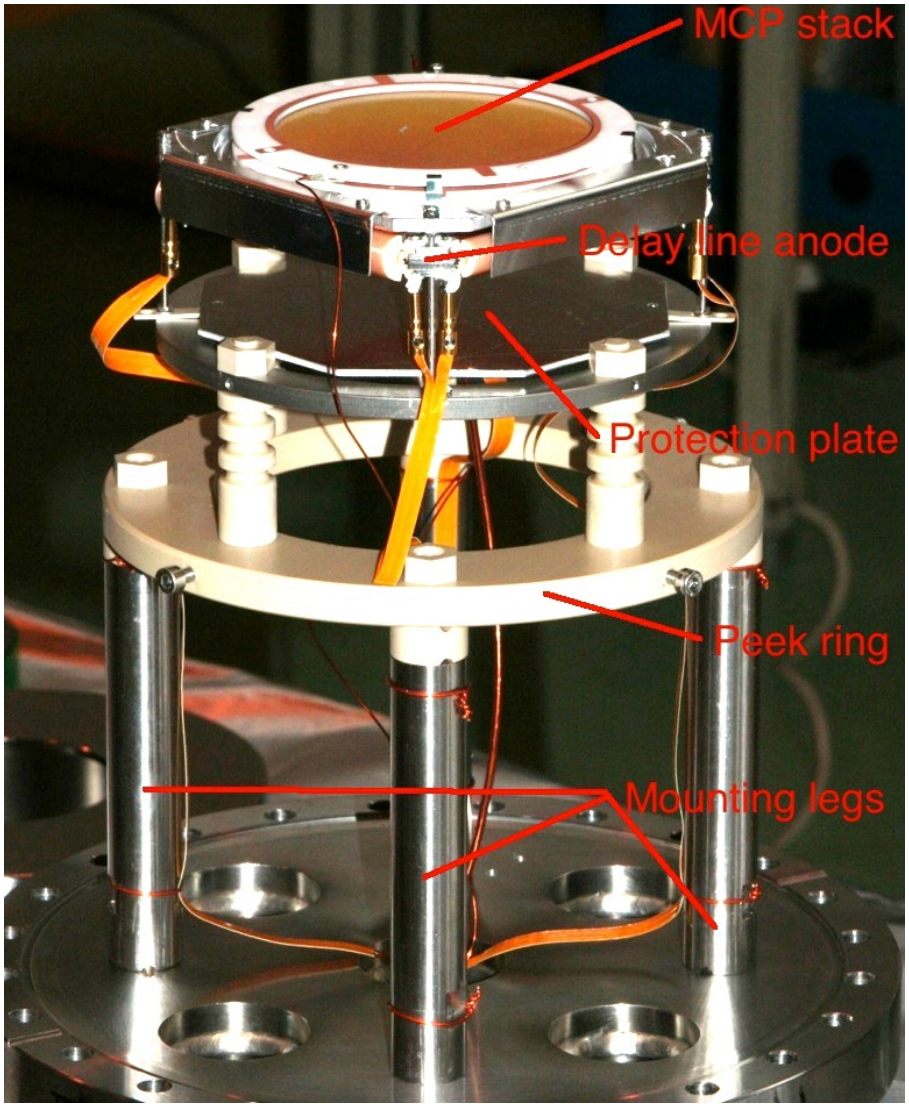
KIT
V. Kozlov
F. Glück

Rez
D. Zákoucký

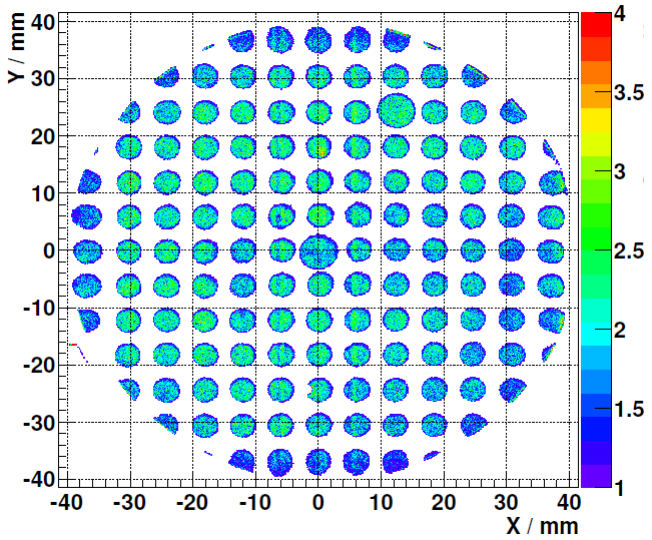
LPC Caen
G. Ban
E. Liénard
X. Flechard
C. Couratin
X. Fabian

KU LEUVEN

Detector - Position sensitive MCP



- 8cm diameter MCP
- 2x2 delay lines for XY, signal and reference for bkg subtraction
- Total efficiency is 40(11)%
- Position resolution 0.2mm
- Relative efficiency calibrated



PhD work, P. Friedag, U. Münster

KU LEUVEN

Ions simulations – tracking

- 3D calculations take 2000× more time than 2D
- Efficient 3D tracking:
  - switching between 2D and 3D routines
  - 3D interpolation using potential map
  - map of potential difference (with-without element) from 3D calculations
  - adding this difference to 2D calculations

→ 3D simulations only 20% longer

Implemented by Paweł Bączyk